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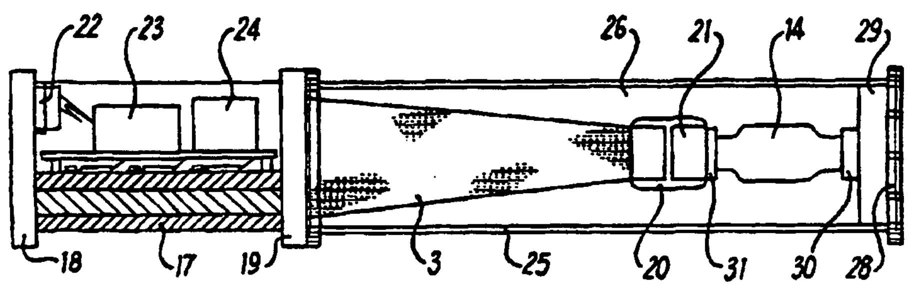
(54) Title: A MOBILE X-RAY UNIT



(57) Abstract

A mobile X-ray unit (36) is described. The unit (36) includes a low voltage direct current power supply (1), an invertor (2) coupled to the power supply (1) and a rectifier (3) coupled to the invertor (2). The invertor (2) converts the low voltage direct current from the power supply (1) to alternating current and the rectifier (3) converts the alternating current to high voltage direct current. An X-ray source (14) is also provided which is energised by the high voltage direct current from the rectifier (3). The unit (36) also has coupling means (24) to permit the unit (36) to be coupled to a translation means (33) which propels the unit (36). The unit (36) is particularly useful for insertion into a tubular member for non-destructive testing of the tubular member.

"A Mobile X-Ray Unit"

This invention relates to X-ray units, and in particular, but not exclusively, for non-destructive testing (N.D.T.).

When steel has been fabricated, it is desirable, and frequently mandatory, that the steelwork and/or welds therein be subjected to non-destructive testing (N.D.T.) to verify the integrity of the steelwork and/or welds. In the case of pipes, tubes and ducts, N.D.T. equipment may be inserted into the bore of the pipe or other tubular article on a mobile unit known as a "pig" or a "pipe crawler" (hereinafter collectively referred to as a "crawler"). A common form of N.D.T involves X-raying of the articles under test. Use of a gamma source for the generation of X-rays has the disadvantages of being a permanent radiation hazard, and of being subject to special regulatory controls. Electrical generation of X-rays overcomes some of the hazards of radio-isotopes, but conventional electrically-powered X-ray sources have their own disadvantages, as will now be detailed.

Past and present X-ray crawlers have been designed and

built around an X-ray tube. These tubes are usually of the half-wave self-rectifying low-frequency type which work on 50-60 Hz chopped battery or direct AC volts into a large step up transformer (120V DC in ≈160,000V AC out), have not changed in design in almost forty years, and are the only type of X-ray tubes currently available for use with crawlers or mobile use.

The existing tube rectifies on each half of the positive cycle 0-160 kV, then back to 0 kV. The purity of the subsequent X-ray beam output suffers as a result of this inefficient process. If radiography requires 140 kV to produce a film, then a substantial part of 0-140 kV-0 produced is wasted energy. The efficiency of this type of unit is less than 10%. This has always been accepted by industry as the standard because, to date, it has not been possible to produce X-rays in any other form that is portable or for crawlers. Constant-potential radiography has always been reserved for expensive equipment laboratories and hospitals in which the equipment is not intended to be portable. The high cost and size of constant-potential units have also been an inhibiting factor as regards development of a portable unit. For example, a typical conventional 160 kV constant-potential X-ray tube would fill an 8′ x 8′ area with oil tanks and high voltage generators.

At present all "portable" X-ray sets are very bulky, heavy and require a generator to power the unit. The X-ray head will typically weigh in excess of 55kg. This is due to the requirement of a very large transformer in the head together with cooling oil and a steel case for strength. The control panel also weighs

about 40kg and requires 120V AC - 240V AC at 50/60Hz. The disadvantages of current X-ray technology are:-

(i) Weight: the large battery packs that are required to drive the already bulky system compound the problem by adding more weight to the system. The sheer weight makes manoeuvrability a problem.

(ii) Dangerous Voltages: the 120V DC batteries currently used are potentially dangerous in that they can cause shock or severe burning.

(iii) Relay Usage: the inherent problem with present-day relay usage is the high voltage used. This generates sparks across the contacts which, in turn, creates a burning effect.

In accordance with a first aspect of the invention a mobile X-ray unit for insertion into a tubular member to irradiate the tubular member with X-rays, comprises a low voltage direct current power supply; an invertor coupled to the power supply, the invertor converting the low voltage direct current from the power supply to alternating current; rectifier means coupled to the invertor, the rectifier converting the alternating current to high voltage direct current; and an X-ray source coupled to the rectifier to receive the high voltage direct current from the rectifier to generate X-rays; and coupling means to couple the unit to translation means which propels the unit within the tubular member.

Preferably, the translation means is in the form of a crawler unit which propels the X-ray unit within the tubular member.

Typically, the tubular member is a pipe, tube or duct which is preferably metallic.

According to a second aspect of the present invention, there is provided a power supply for an X-ray set, said power supply comprising an invertor means, d.c. (direct current) supply means for supplying d.c. to said invertor means for conversion of said d.c. to a.c. (alternating current), and rectifier means coupled to receive said a.c. from said invertor means, said invertor means functioning in use to convert said a.c. to h.v.d.c. (high voltage d.c.) suitable for energising an X-ray source.

Said invertor means is preferably a pulse-width-modulated high-frequency oscillator. Coupling means coupling a.c. from said invertor means to said rectifier means may comprise an e.h.t (extra high tension) transformer converting said a.c. from said invertor means to high voltage a.c. having a square-wave voltage waveform, the coupling means preferably further comprising one or more series-connected chokes between said invertor means and said e.h.t transformer.

In accordance with a third aspect of the invention, a rectifier for an X-ray unit comprises a number of capacitors, a number of diodes coupled across the capacitors, and a number of resistors coupled in series to the capacitors and diodes, the capacitors, diodes

and resistors being encapsulated in an insulating solid.

The rectifier may comprise a multiplier rectifier, preferably a Cockroft-Walton ladder network. Said multiplier rectifier preferably comprises a feedback tapping intermediate the input and the output of said multiplier rectifier, whereby to provide a measure of the high voltage direct current (h.v.d.c) without directly tapping the output of the multiplier rectifier.

Preferably, the insulating solid may be a resin, such as an epoxy resin. Typically, the resin may include a filler to enhance the dielectric strength of the solid. The filler may comprise alumina. Preferably, the insulating solid does not suffer substantially from long term degradation due to temperatures of up to 100°C.

The direct current power supply preferably comprises a direct current regulator means operable to receive an input direct current of relatively widely variable voltage, and to deliver an output direct current to said invertor means at a relatively constant voltage. The regulator means preferably comprises means for receiving feedback signals from the rectifier means, the feedback signals representing the output voltage and/or the output current of the rectifier means, the regulator means preferably functioning automatically in response to the feedback signals to vary the output thereof in a sense which tends to diminish variations of the h.v.d.c from demanded levels thereof.

In accordance with a fourth aspect of the invention, an X-ray unit comprises an X-ray source having a cathode and an anode, wherein the cathode is earthed and a low voltage direct current heater current is applied to the cathode, and a high voltage direct current is applied to the anode.

The X-ray source is preferably an evacuated thermionic device wherein X-rays are generated in use by the impact of electrons on an anode maintained at high voltage with respect to a thermionic source of the electrons electrically connected as the cathode of the device.

According to a fifth aspect of the present invention, there is provided an n.d.t X-ray set for the non-destructive testing of pipes, tubes, ducts and the like by means of X-rays sourced therein, said X-ray set being in the form of a pipe crawler, said crawler comprising a wheeled trolley dimensioned to fit within the bore of the pipe, tube, duct or the like, and to be controllably mobile along said bore, said trolley mounting an X-ray set in accordance with the second aspect of the present invention.

An example of a mobile X-ray unit in accordance with the invention will now be described with reference to the accompanying drawings, in which:-

Fig. 1 shows a graph of penetration of X-rays from a chopped DC power supply;

Fig. 2 shows a graph of penetration of X-rays from a constant potential power supply;

Fig. 3 is a schematic block diagram of the

electronic components of an X-ray power supply;

Fig. 4 is a side view showing the physical construction of the power supply of Fig. 3;

Fig. 5 is a side view similar to Fig. 4, but with the multiplier and X-ray tube enclosed;

Fig. 6 is a side view of a crawler unit;

Fig. 7 is a side view of a battery unit; and,

Fig. 8 is a side view of a retrieval unit.

Practical objectives of the X-ray unit described below are:-

(i) To introduce an X-ray tube, using switch mode high frequency generators to produce a constant potential regulated panoramic X-ray beam.

(ii) To power the unit with a 24V DC battery pack.

Figs. 1 and 2 show penetration charts of depth of penetration into a 12" steel pipe for a conventional chopped DC X-ray unit and a constant potential unit, respectively. In both cases the voltage is 160kV at a current of 5mA.

The constant potential tube used has the following characteristics:

(i) small;
(ii) lightweight;
(iii) robust;
(iv) low cost;
(v) achieves 75-85% efficiency;
(vi) is capable of producing laboratory results

on-site with portable crawlers.

A specification and description for a 800W, 160kV high voltage power supply for an X-ray generator now follows.

The system comprises three basic functional blocks (see Fig. 3). These are:

(i) a boost section 1,
(ii) an invertor 2, and
(iii) a high voltage multiplier rectifier 3.

In addition, incoming power passes through an RFI filter 13 before entering the boost section, and a EHT transformer 4 provides an interface between the invertor 2 and the multiplier 3. Boost section electronics 12, invertor control electronics 9 and main control electronics 11 are also provided.

The boost section 1 is used to allow compatibility between 24V and 120V input versions by converting input voltages of 24V up to a nominal 120V. The boost section 1 automatically distinguishes between 24 and 120v supplies.

The invertor 2 is a pulse-width-modulated high-frequency oscillator of standard design adapted to suit the appropriate power levels. The output from this is fed via series chokes to the transformer 4 where it is stepped up to a variable amplitude square-wave for driving the multiplier 3.

The high voltage multiplier 3 is based on a

conventional Cockroft-Walton ladder and increases the voltage to 160kV, indicated as EHT output 5 in Fig. 3.

The EHT output 5 is controlled using a partly closed-loop system 6. The closed loop system 6 comprises a current feedback line 7 and a voltage feedback line 8 coupled to the invertor control electronics 9. The invertor control electronics 9 is coupled by line 10 to the main control electronics 11. To avoid the necessity of a chain of resistors to the EHT output, the voltage at the third stage of the multiplier is maintained at the demand level. The effect of this is that when the output load increases, the EHT output 5 also increases proportionately. This may be compensated to good precision by the addition of a surge-limiting resistor (not shown) in series with the output 5.

The physical construction of the unit is shown in Figs. 4 and 5 which also include an X-ray tube 14. The main electronics, with the exception of the multiplier (or high voltage ladder) 3, are mounted on a platform 15 which is bolted by bolts 16 to a heat sink assembly 17. The heat sink assembly 17 is mounted between two plates 18, 19 and the multiplier 3 is mounted to the opposite side of plate 19 from the heat sink assembly 17.

The multiplier 3 comprises a Cockroft-Walton ladder comprising diodes, capacitors and resistors encapsulated in an epoxy resin with an alumina filler. The alumina helps increase the dielectric strength of the encapsulation material. The encapsulation material preferably may withstand temperatures of up to 100°C without suffering substantial long term degradation.

Coupled to the end of the multiplier 3 opposite plate 19, is a voltage stress shredder 20 and a thermal tube contact 21. Anode end 31 of the tube 14 is mounted on the contact 21.

Attached to plate 18 is a 24-way connector 22 which is connected to the RFI filter 13 in the electronics. The electronics on the platform 15 consist of a power supply unit 23 which comprises the RFI filter 13, boost section 1, invertor 2 and transformer 4, and a control unit 24 which comprises the control electronics 9, 10, 12.

Fig. 5 shows the multiplier 3 and tube 14 encased in a metal cylinder 25 which is filled with a coolant/isolator 26 which is in the form of a gas. Typically, the gas may be sulphur hexaflouride, known as SF6. The metal cylinder 25 bolts directly on to the plate 19 using holes 27 in the plate 19. The cylinder 25 has an end plate 28 with an insert 29 in which cathode end 30 of the tube is coupled.

Specification of the X-ray unit is as follows:-

(i) Input requirements: 20V to 24V DC at approximately 45 to 50 Amps, or 100V to 140V DC at 9 to 10 Amps, depending on load. Automatic supply detection is incorporated.

(ii) control signals: TTL compatible high

voltage (HV) ON/OFF control. Logic "0"= ON.

TTL compatible HV OK signal. Logic "0"=OK.

Basic diagnostic function active when HV active.

Demand signal. Ground referenced 0 to + 5V signal. 5-V represents 160KV. Accuracy better than 2.5% target at 5mA load.

Current monitor. Ground referenced 0 to + 5V signal where 5V represents 5mA HT current. Accuracy better than 2.5% target.

(iii)	Output voltage:	0 to + 160kV proportional to demand signal. Current load 0 to 5mA. Ripple voltage <2.5% peak to peak target at 60 kHz. Regulation <2.5% target zero to full load and <1% over supply range.

An advantage of the unit described above is that it uses a common cathode arrangement. Hence, the diodes in the Cockroft-Walton ladder are inverted. The common cathode arrangement has the advantage that it permits direct control of the heater on the cathode and does not have the problems associated with isolation of the

heater voltage and the high voltage of 160kV.

Although the example described above is for a 160kV unit other voltage units could be designed by making appropriate changes to the power supply unit and control electronics.

Fig. 6 shows the apparatus of Figs. 4 and 5 incorporated into a crawler unit 32. The unit 32 comprises a drive unit 33 having driven wheels 34 and a control panel 35. The drive unit 33 is mechanically and electrically coupled to an X-ray unit 36 in which the apparatus of Figs. 4 and 5 is located. The X-rays are emitted around the circumferential section 37 of the unit 36. The X-ray unit 36 is coupled to a tell tail unit 38 which incorporates freely rotating wheels 39.

Fig. 7 shows a battery box unit 40 for coupling to the drive unit 33 for supplying power to the drive unit 33 and X-ray unit 36. The unit 40 has wheels 41 and a retrieval ring 42 on one end.

Fig. 8 shows a retrieval unit 43 having a harpoon 44 which can engage with the retrieval ring 42. If the crawler unit becomes stuck or stops within a pipe, the retrieval unit 43 may be dispatched down the pipe so that the harpoon 44 engages the retrieval ring 42 to permit the crawler unit, comprising units 33, 36, 38, 40 to be retrieved from the pipe.

CLAIMS

1. A mobile X-ray unit for insertion into a tubular member, the unit comprising a low voltage direct current power supply; an invertor coupled to the power supply, the invertor converting the low voltage direct current from the power supply to alternating current; rectifier means coupled to the invertor, the rectifier coverting the alternating current to high voltage direct current; and an X-ray source coupled to the rectifier to receive the high voltage direct current from the rectifier to generate X-rays; and coupling means to couple the unit to translation means which propels the unit within the tubular member.

2. A mobile X-ray unit according to Claim 1, wherein the translation means is in the form of a crawler unit which propels the X-ray unit within the tubular member.

3. A mobile X-ray unit according to Claim 1 or Claim 2, wherein the power supply comprises a battery pack coupled to the translation means.

4. A mobile X-ray unit according to any of the preceding Claims, wherein the rectifier is encapsulated in an insulating solid.

5. A mobile X-ray unit according to Claim 4, wherein the insulating solid comprises an epoxy resin.

6. A mobile X-ray unit according to Claim 4 or Claim 5, wherein the insulating solid includes a filler material to enhance the dielectric strength of the insulating solid.

7. A mobile X-ray unit according to Claim 6, wherein the filler material comprises alumina.

8. A mobile X-ray unit according to any of the preceding Claims, wherein the rectifier comprises diodes, capacitors and resistors arranged to form a Cockroft-Walton ladder.

9. A mobile X-ray unit according to any of the preceding claims, wherein the X-ray source comprises an anode and a cathode, the high voltage direct current being applied to the anode and the cathode is grounded.

10. A mobile X-ray unit according to Claim 9, when dependent on Claim 8, wherein the diodes in the Cockroft-Walton ladder are inverted.

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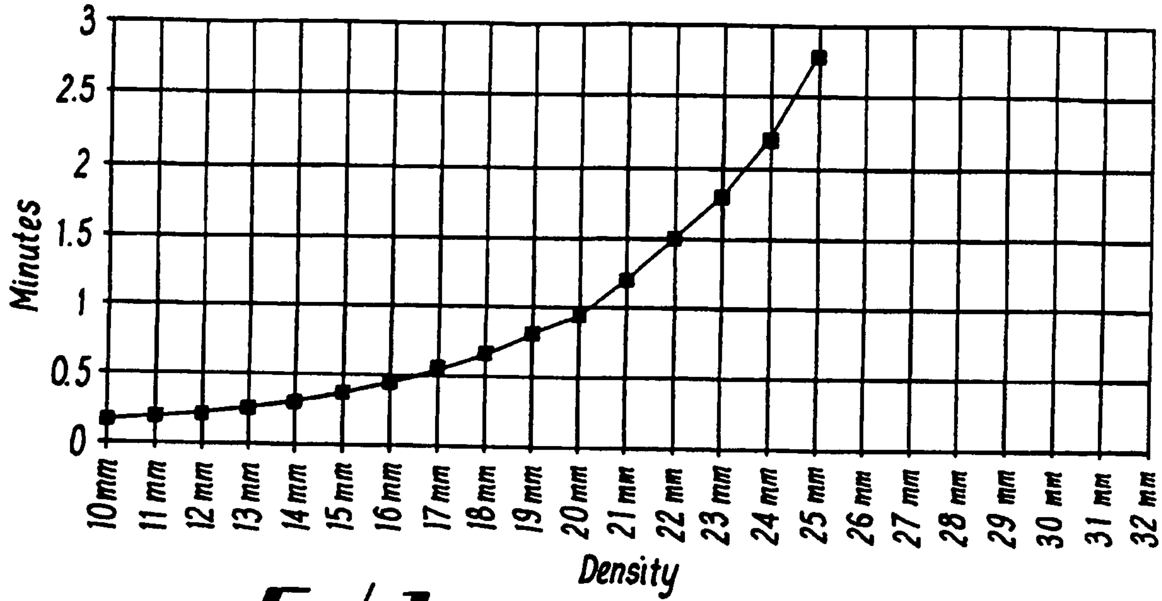
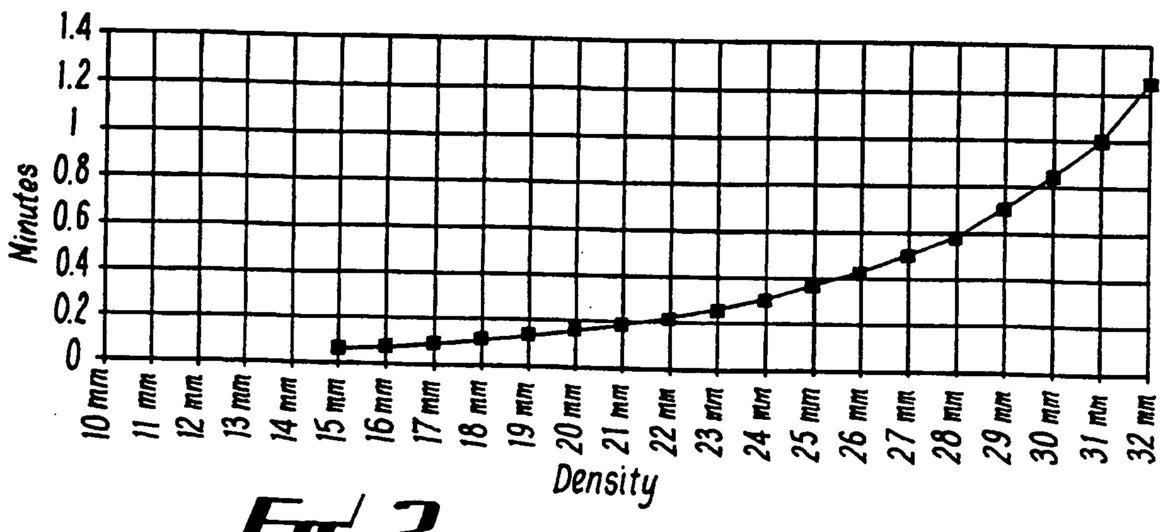

3
2.5
2
1.5
1
0.5
0
Minutes
10mm
11 mm
12mm
13mm
14mm
15mm
16mm
17mm
18mm
19mm
20mm
21 mm
22 mm
23 mm
24 mm
25 mm
26 mm
27 mm
28 mm
29 mm
30 mm
31 mm
32 mm
Density

FIG.1


1.4
1.2
1
0.8
0.6
0.4
0.2
0
Minutes
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11 mm
12 mm
13 mm
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15 mm
16 mm
17 mm
18 mm
19 mm
20 mm
21 mm
22 mm
23 mm
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25 mm
26 mm
27 mm
28 mm
29 mm
30 mm
31 mm
32 mm
Density

FIG.2

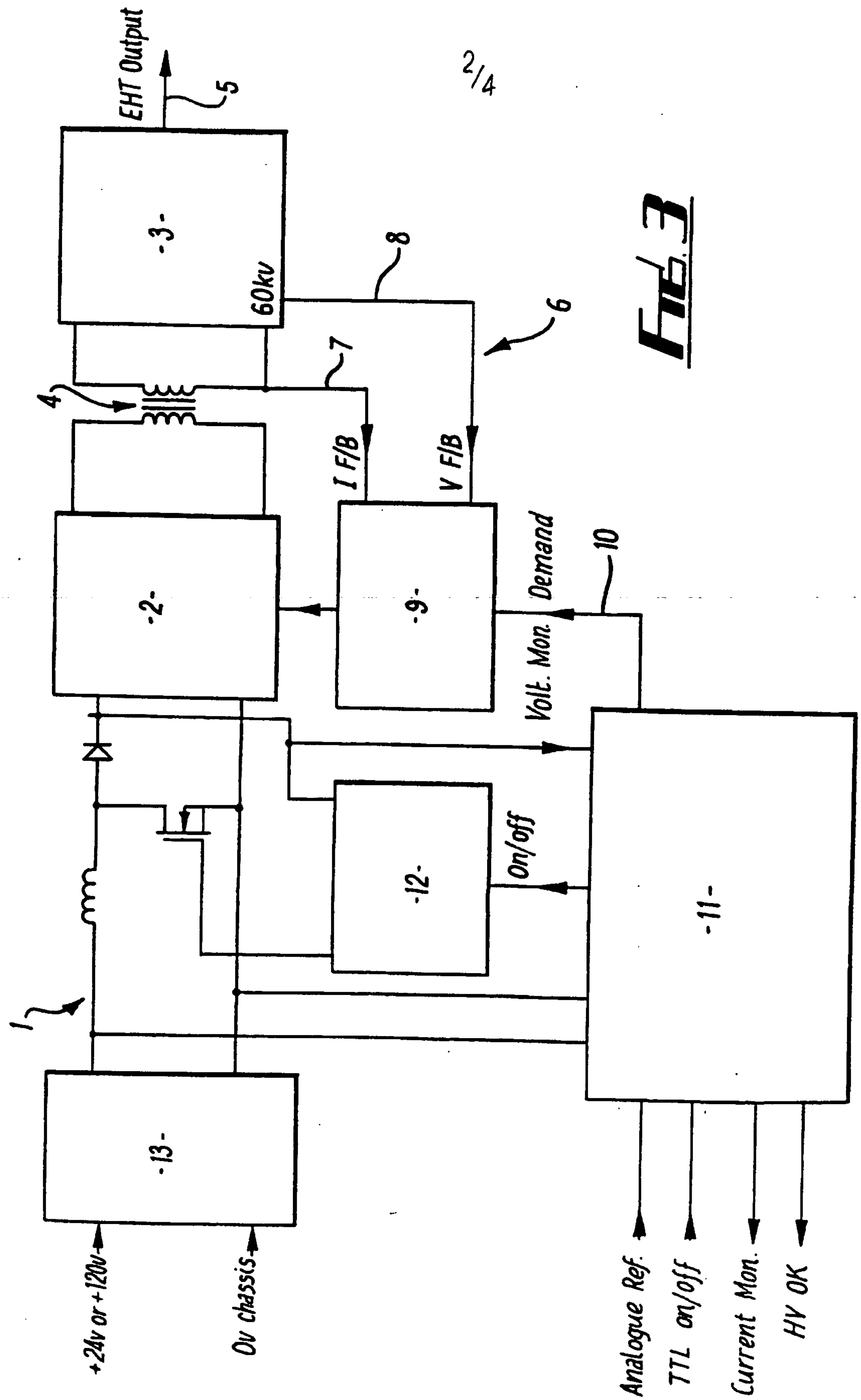
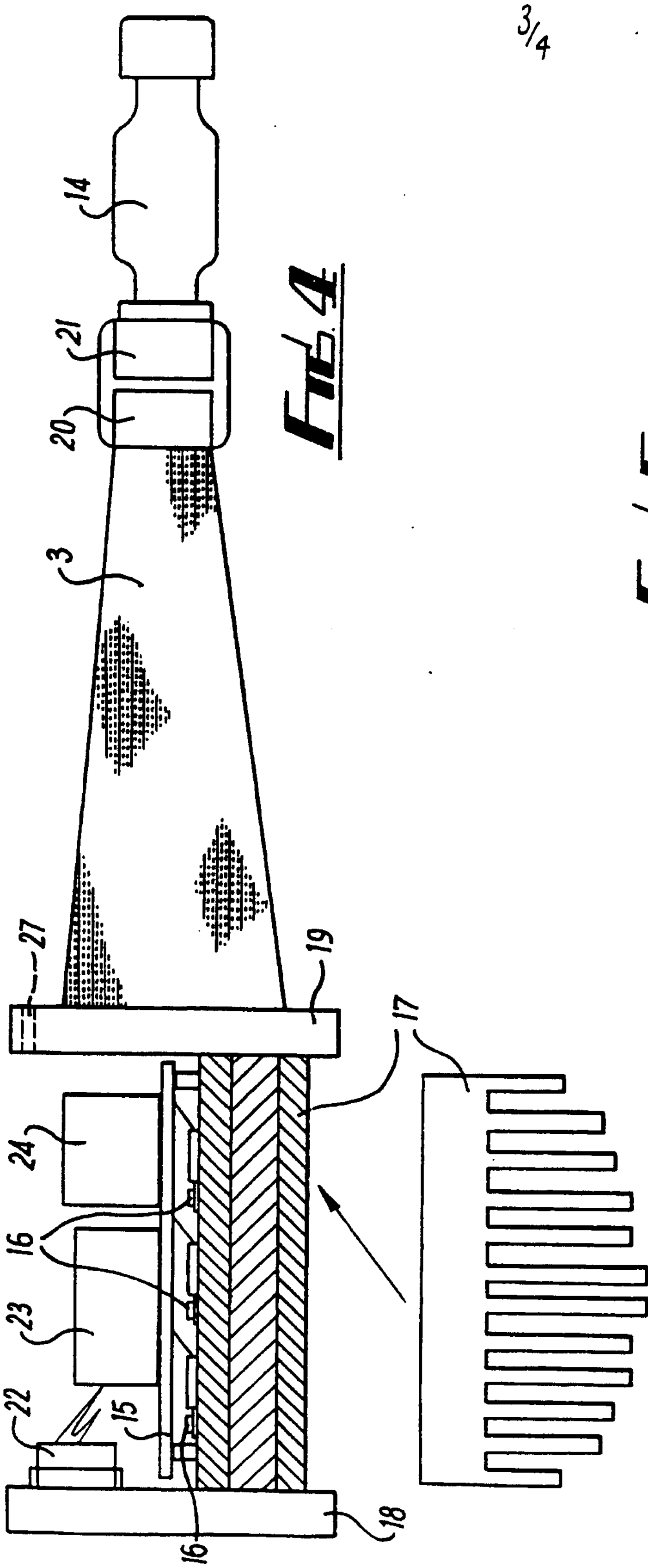

EHT Output
5
-3-
60kv
8
6
7
4
I F/B
V F/B
-2-
-9-
Demand
10
Volt. Mon.
on/off
-12-
-11-
1
-13-
+24v or +120v
0v chassis
Analogue Ref.
TTL on/off
Current Mon.
HV OK

Fig. 3


14
21
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3
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19
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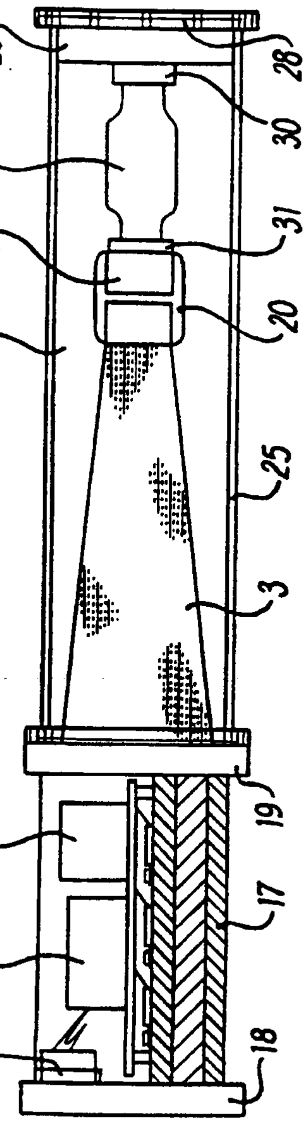
15
16
18

FIG. 4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22
18

FIG. 5

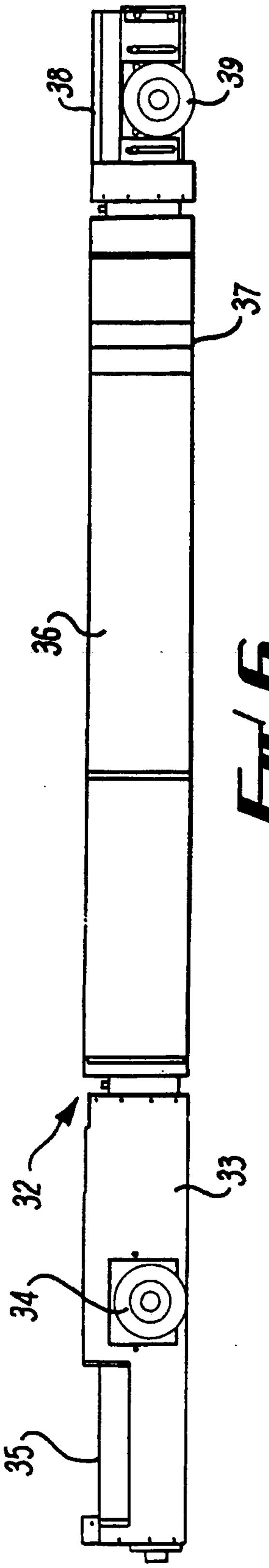

Fig. 6

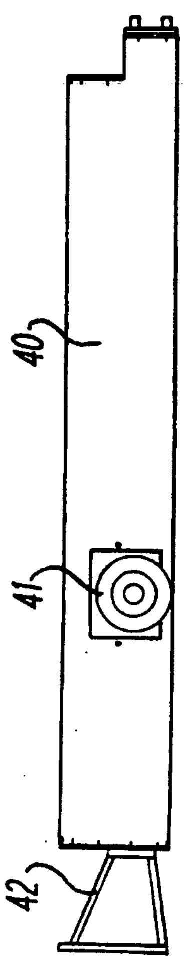

Fig. 7

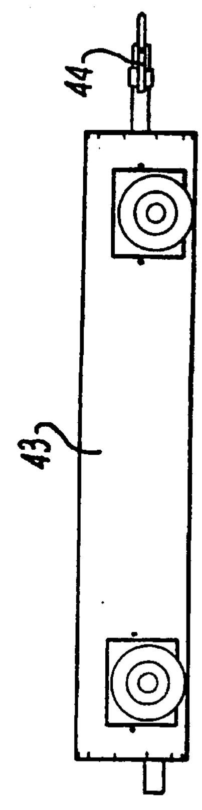

Fig. 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/02087

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H05G1/10 G01N23/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H05G G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A,4 694 480 (B. SKILLICORN) 15 September 1987 see column 1, line 47 - column 2, line 59 see column 5, line 33 - column 6, line 57	1,2,4,9
A		8,10

Y	US,A,3 691 385 (T.E. KETCHBAW ET AL.) 12 September 1972 see column 1, line 3 - line 58 see column 2, line 31 - line 64	1,2
A		3

Y	EP,A,0 488 991 (XI TECH INC.) 3 June 1992 see abstract see column 5, line 8 - column 6, line 26 see column 11, line 31 - column 12, line 56	4,9
A		1

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
18 January 1995	25.01.95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Horak, G

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/02087

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,3 904 878 (C.A. BURCH ET AL.) 9 September 1975 see abstract	1,2
A	US,A,4 797 907 (R.L. ANDERTON) 10 January 1989 see column 9, line 65 - column 10, line 49 see column 12, line 41 - column 13, line 38; figures 2,6,8	1,9
A	GB,A,1 321 844 (CORROSION & WELDING ENGINEERING LIMITED) 4 July 1973 see page 1, line 33 - page 2, line 62	1,2
A	EP,A,0 405 399 (KABUSHIKI KAISHA TOSHIBA) 2 January 1991 see column 11, line 42 - column 12, line 50	1,4,8-10
A	US,A,5 077 771 (B. SKILLICORN ET AL.) 31 December 1991 see column 3, line 27 - column 5, line 2	1,4,9
A	EP,A,0 429 315 (VARIAN ASSOCIATES, INC.) 29 May 1991 see abstract see page 7, line 46 - page 8, line 39; figures 1,3A	1,9

INTERNATIONAL SEARCH REPORT

Int[illegible]onal Application No
PCT/GB 94/02087

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-4694480	15-09-87	NONE		
US-A-3691385	12-09-72	NONE		
EP-A-0488991	03-06-92	DE-A-	3782088	12-11-92
		EP-A,B	0247758	02-12-87
		JP-A-	63299100	06-12-88
		US-A-	4856036	08-08-89
		US-A-	4979198	18-12-90
US-A-3904878	09-09-75	NONE		
US-A-4797907	10-01-89	NONE		
GB-A-1321844	04-07-73	NONE		
EP-A-0405399	02-01-91	US-A-	5272612	21-12-93
		JP-A-	3095898	22-04-91
		US-A-	5105351	14-04-92
US-A-5077771	31-12-91	NONE		
EP-A-0429315	29-05-91	CA-A-	2030582	25-05-91
		JP-A-	3284167	13-12-91
		US-A-	5023768	11-06-91